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Review Essay

Geoengineering: A critique

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Geoengineering the Climate: Science, Governance and Uncertainty. The Royal Society, Report 10/09, RS1636, September 2009, ISBN 978-0-85403-773-5.

The Royal Society report on geoengineering is one of the most important documents concerning climate change of recent years. Its ninety-three pages provide a clear, well-written, thoroughly researched and referenced, and authoritative overview of the various techniques that have been proposed for manipulating the climate and artificially cooling the planet. The report summarizes the science and technology of each technique, and conveniently brings together the best current estimates of their costs, risks, and effectiveness, enabling an informed comparison to be made. Throughout the report the authors display a detailed and comprehensive understanding of the science and policy issues they describe, while also highlighting the many aspects of current knowledge which are uncertain, and where estimates or conclusions must be treated as preliminary, or with a pinch of salt. All in all, it makes for a very attractive mix of explanation and critical analysis. Combined with the fine writing style and pleasant layout, the reader is painlessly and quickly brought up to speed on this radical, but increasingly important topic. The report is certain to take a central place in future policy debates, and quite rightly so. Nevertheless, its conclusions and recommendations do not entirely reflect the data upon which they rest.

The report begins with a summary and then an introduction to the notion of geoengineering. This is defined, fairly non-controversially, as "deliberate large-scale intervention in the Earth's climate system, in order to moderate global warming".[1] As the introduction notes, this idea has been around for a while, but in recent decades there has been an explosion of ideas as to how it might be achieved, some of them—such as placing millions of mirrors between the sun and the Earth—with an almost science-fiction aura, although based on serious science and

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[1] Page ix. The origin of the term is usually traced to C. Marchetti, *On Geoengineering and the CO_2 Problem*, Research Memorandum RM-76-17, International Institute for Applied Systems Analysis, Vienna (1976).

being researched by distinguished scientists.[2] Yet despite the proliferation of suggestions, and a growing number of thoughtful publications, research remains at a very early stage, and there is no technique to which high confidence attaches about its safety, chance of success, or cost. As it is put on page 4 of the report:

> Given the current poor state of understanding about geoengineering science, potentially useful techniques could be prematurely dismissed out of hand, and dangerous proposals may be promoted with enthusiasm. Policymakers need well-informed and authoritative advice based on sound science.

The subsequent sentence states:

> With growing concern that geoengineering options were being promoted by some as a possible 'solution' to the problem of climate change, that experiments were being undertaken, in some cases potentially in contravention of national or international laws, and that active investment in the development and testing of new technologies is occurring, the Royal Society decided to undertake an independent scientific review of the subject.

One goal of the report may be to contribute to combating global warming by helping to identify potentially useful geoengineering technologies. However, the quotation above suggests that an equal concern of the Royal Society is to prevent laws being broken and money being wasted on silly or dangerous experiments. Certainly, it would be undesirable if large scale experimental meddling with the climate or biosystems were to be undertaken without either adequate science or governance frameworks, let alone international agreement (ignoring for the moment that this is also a reasonable description of fossil-fuel use). The fear of resulting environmental harm is a legitimate concern. Yet its prominence here is odd. Should there be a report about geoengineering in order to assess its potential to combat climate change, or because irresponsible experiments may be harmful? Which is the more burning policy issue right now? There is a hint here that geoengineering may be regarded as at least as important a problem as it is an answer—an issue which is returned to below.[3]

The first two substantive chapters of the report deal with the different kinds of geoengineering. These are usefully divided into techniques which aim to remove carbon dioxide from the atmosphere, called carbon-dioxide reduction methods (CDR), and those which aim to reflect sunlight back from the Earth, thereby cooling it. These are called solar-radiation management methods (SRM).

[2] See for overviews, e.g., T. M. Lenton and N. E. Vaughan, *The Radiative Forcing Potential of Different Climate Geoengineering Options*, 9 Atmospheric Chemistry and Physics 5539 (2009); Stephen H. Schneider, *Geoengineering: Could We or Should We Make it Work?*, 366 Philosophical Transactions of the Royal Society 3843 (2008); Alan Carlin, *Global Climate Change Control: Is There a Better Strategy than Reducing Greenhouse Gas Emission?*, 155 U. Pa. L. Rev. 1401 (2007); Paul Crutzen, *Albedo Enhancement by Stratospheric Sulfur Injections: A Contribution to Resolve a Policy Dilemma?*, 77 Climatic Change 211 (2006); *Policy Implications of Greenhouse Warming—Mitigation, Adaptation, and the Science Base*, National Academy of Sciences, Committee on Science, Engineering, and Public Policy, ch. 28 (1992).

[3] See the discussion of moral hazard at text to note 41, and the concluding part of this review.

The CDR chapter is not very optimistic. The initial proposal considered is reforestation. This is not always thought of as geoengineering, but since it is a way of absorbing carbon dioxide, the report considers its effects. The conclusion is that it is both cheap and desirable, but will not have a great effect on carbon dioxide levels. Its effectiveness is rated as "low".[4] This is also the rating provided to biochar production.[5] Biochar is a form of charcoal made by heating organic matter in the absence of oxygen. This has a long history, and is traditionally done by letting biomass smoulder under a layer of soil, although there are other methods. The process locks atmospheric carbon into a stable, powdery charcoal, which has various uses. It amounts to replenishing the fossil fuels that we are burning, an attempt to "run the movie backward".[6] Looking at it like this makes it clear just how much biochar would have to be produced to compensate for current fossil-fuel use, and this is the report's fundamental criticism. In theory, biochar production could fully counteract anthropogenic emissions, but in practice its use is limited by constraints on land availability and cost, and potential conflicts with other land uses, notably agriculture. The report ultimately concludes that it is unlikely that it will make a "large" contribution to atmospheric carbon reduction.[7]

Ocean fertilization is the watery equivalent of terrestrial carbon sequestration methods. By adding iron or phosphorus to the oceans, we can stimulate the growth of various organisms. In growing they would absorb carbon dioxide, and when they died the carbon would fall to the seabed with them. However, while this idea grabbed the headlines a few years ago, more recent research casts doubt on its effectiveness, and the Royal Society's report shares this doubt, and also notes that it would have the added downside of potentially serious disturbance to aquatic ecosystems.[8] It is also, of all the geoengineering methods discussed, the one with the most obvious associated legal problems, for various conventions and treaties would apply to activities influencing the composition of the seas.[9]

There are just two CDR methods which the report suggests could make a significant contribution to carbon dioxide reduction: enhanced weathering, and carbon dioxide scrubbing. The first of these consists of adding minerals to the sea or land to stimulate the process by which silicate rocks change to carbonate rocks (weathering). This process results in carbon being locked up in the rocks. There is enough silicate on the planet that the maximum potential impact of this method is more or less unlimited, the report suggests. It could, in theory, have a very high impact on carbon dioxide levels. However, in order to achieve this, a scale of mineral production, distribution, and mixing would have to be achieved that would be very expensive and bring environmental

[4] Page 11.
[5] Page 13.
[6] Bill McKibben, on the homepage of <www.biochar-international.org>.
[7] Page 12.
[8] Pages 17-18.
[9] See page 42. See also James Edward Peterson, *Can Algae Save Civilization? A Look at Technology, Law and Policy Regarding Iron Fertilization of the Ocean to Counteract the Greenhouse Effect*, 6 Colo. J. Int'l Envtl L. and Pol'y 61 (1995); Karen Scott, *The Day After Tomorrow: Ocean CO_2 Sequestration and the Future of Climate Change*, 18 Geo. Int'l Envtl. L. Rev. 57 (2005).

disadvantages of its own. The report speaks of mining on a scale equal to or greater than current coal and cement production in order for the method to be "quantitatively important".[10] The conclusion is that enhanced weathering is likely to be more expensive than most other options.[11]

This leaves carbon-dioxide scrubbing, that is, the absorption of carbon dioxide from the atmosphere by specially designed machines of various kinds. These might be "artificial trees" which can absorb ambient carbon dioxide, or devices which scrub carbon dioxide from the exhaust gases of power stations, factories, or any large fossil-fuel-powered motor. The scale of the impact of such devices is of course entirely dependent upon the scale of their deployment.

The report adopts a distinction between carbon capture at source (CCS), which it does not consider to be geoengineering—presumably because the CO_2 never reaches the atmosphere—and therefore does not consider in depth, and capture from the ambient air, which it does. However, both rely to some extent on similar technologies for the absorption, transport, and ultimate storage of the captured CO_2, and it is clear that both are feasible. It is a question of cost, and, in the case of ambient-air capture—which might involve millions of "trees" globally—of the aesthetic impact of the capture devices. The report quite reasonably points out that this technology is likely to develop quickly, and that the number and costs of the devices necessary may well come down significantly.

Given the potential of ambient carbon capture it would have been welcome to see more than the page or two that the report contains on the subject. Some more detail on the options and their problems would have been worthwhile. Among the ideas circulating in the literature are shipping-container sized units in every city block, or lines of tree-like structures along major roads.[12] Such concrete images do reveal the fundamental inelegance of carbon capture. It lacks the scientific and policy *style* of options which, by contrast, try to leverage or enhance natural processes. It is a brute-force approach, and for that reason deserves to be regarded with a certain suspicion. And yet, consider the fundamental inelegance of just burning stuff to fuel our lives. Maybe a marriage of artificial carbon capture and fossil-fuel combustion is both fitting and balanced. When fossil fuels run out, so will the need for such defensive technology. In the meantime, the report suggests that carbon capture is worth exploring, and could become important if costs can be brought down.[13] It is regrettable that the reader is given no details of what percentage of anthropogenic carbon dioxide might be realistically absorbed and what scale of apparatus this would involve. The potentially "high" effectiveness and "low" affordability remain somewhat ambiguous.[14]

[10] Page 14.

[11] Page 20.

[12] *Geoengineering—Giving Us the Time to Act*, Report by the Institute of Mechanical Engineers (2009), available at <http://www.imeche.org/about/keythemes/environment/Climate+Change/>.

[13] Page 16. Cf. David W. Keith, Minh Ha-Duong, and Joshuah K. Stolaroff, *Climate Strategy with CO_2 Capture from the Air*, 74 Climatic Change 17 (2006).

[14] Page 16, Table 2.7.

The best of the SRM methods are, by contrast with CDR, frighteningly effective and shockingly cheap. They cut out the middleman of carbon dioxide and go straight to the question of temperature, which turns out to be relatively easy to influence. The Earth's albedo—its reflectivity—needs to be increased only by a few percentage points to more than compensate for the warming effect of raised carbon-dioxide levels,[15] and such a reduction could be achieved by a number of means.

Although the range of SRM methods considered in the report is broad, there are two which stand out as by far the most realistic options. One is the enhancement of the natural albedo of clouds. It has been suggested that spraying seawater into the air could change the composition and reflectivity of the droplets in clouds sufficiently that they would shine a little more on top, reflect more shortwave radiation into space, and thereby reduce the greenhouse effect.[16] The striking part of this idea, however, is its proponents' estimate that returning the Earth's temperature to pre-industrial levels would require around 1,500 ships for spraying and cost a few billion dollars per year.[17] This is, in the context of global warming, small change.

It is far from proven that cloud albedo enhancement would work. Estimates vary, and question marks remain, and for this reason the report ultimately estimates its effectiveness as "low to medium".[18] However, as the report itself also notes, the effectiveness of cloud enhancement is uncertain, rather than known to be limited. There is research currently underway which promises significant advances in understanding. In the meantime, views vary on what the likely outcome of this research will be.[19] Both the total effectiveness of the technique, and the extent to which its effects are global rather than local, remain to be seen, but if the optimistic scenarios are correct then this method could entirely stop or even reverse global warming.[20]

The same is true of another SRM technique, the insertion of sulphur (or other) aerosols into the stratosphere. These reflect sunlight, and so have a cooling effect. It is what happens when volcanoes erupt and send particles into the upper atmosphere—the global cooling effect of such eruptions is well-documented. There are various suggestions for how aerosols could be artificially inserted, of which the most optimistic referred to in the report is that of nine adapted military tanker aircraft flying around squirting the stuff out.[21] Others suggest that a somewhat larger number of aircraft would be needed, but there appears to be a consensus that for the cost

[15] Crutzen, supra note 2; T. M. L. Wigley, *A Combined Mitigation/Geoengineering Approach to Climate Stabilization*, 314 Science 452 (2006).

[16] John Latham et al., *Global Temperature Stabilization via Controlled Albedo Enhancement of Low-Level Maritime Clouds*, 366 Philosophical Transactions of the Royal Society 3883 (2008); Stephen Salter, Graham Sortino, and John Latham, *Sea-Going Hardware for the Cloud Albedo Method of Reversing Global Warming*, 366 Philosophical Transactions of the Royal Society 3989 (2008).

[17] Page 27; Salter, Sortino, and Latham, supra note 16.

[18] Page 28, Table 3.3.

[19] Doubts are expressed by Lenton and Vaughan, supra note 2. See also pages 5 and 28 of the report.

[20] See supra note 16.

[21] Page 35.

of at most a few tens of billions of dollars per year the global albedo could be increased to an extent that would take us back to pre-industrial temperatures.[22]

Thus aerosols appear to be another way of stopping or reversing climate change at a cost of a few tens of dollars per year per person in the developed world. The advantage of this method over cloud-enhancement is that somewhat more is known about the relevant science, and there is broad agreement that it would work, which is why the report puts its effectiveness at "high".[23]

A useful table on page 35 of the report highlights the power of these SRM proposals. Both are costed at 200 million dollars per year per unit of radiative forcing (a measure of temperature change), and it is noted that the degree of cooling which could be achieved by the sulphur method is "unlimited". By comparison, the cost per unit of radiative-forcing of reduction by conventional mitigation is estimated at 200 billion dollars per year—one thousand times greater. The cost of SRM, or rather its relative cheapness, is in a league of its own. Countering a doubling of atmospheric carbon dioxide might cost around 800 billion dollars per year via the emissions-reduction route, or less than a billion dollars per year by spraying some sulphur around.

Alas, of course, it is not so simple. For a start, the cost estimates are deeply speculative. For the costs of emissions reduction the report relies on the Stern Report, which is indeed the most authoritative estimate.[24] However, other research puts these costs much lower, not least because of the positive spin-offs in terms of the social and technological change that they entail.[25] There is much to be said for the view that instead of seeing the immediate price of the steps necessary for emissions reduction as a true cost, it should rather be regarded as an investment in a cleaner, more efficient, and ultimately better-off world. Mitigation is a catalyst for a social, environmental, and technological transformation, the long-term benefits of which make a short-term rise in energy costs seem trivial.

Analogous arguments can be made about geoengineering. The capacity to control temperature and manage side-effects would have such a broad impact on our society that the upfront costs are hardly the point. Thus maybe it is really not worth comparing such costs at all. The report's authors were clearly aware of these problems, for they concede the enormous problems with evaluating true costs. The table on page 35 is intriguing but it is hard to know what to do with the information. The real impact of the figures is not to tell us which approach is best, or even ultimately cheapest, but to display how very accessible SRM is. It is difficult to maintain that an option which requires so few initial resources for the achievement of such an effect is going

[22] Page 32. See also Crutzen, supra note 2; Lenton and Vaughan, supra note 2.
[23] Page 31.
[24] Nicholas Stern, The Economics of Climate Change: The Stern Review (2007), pages 35, 37, 44.
[25] Ottmar Edenhofer, Kai Lessmann, and Nico Bauer, *Mitigation Strategies and Costs of Climate Protection: The Effects of ETC in the Hybrid Model MIND*, 207 The Energy Journal (2006), special issue on Endogenous Technological Change and the Economics of Atmospheric Stabilisation; B. Metz et al., eds., *Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change 2007*, chapter 11 (2007).

to be easy to ignore. As the report and many other authors point out, it is within the reach of even a rich individual, or a corporation, and certainly a single state.[26] Lack of a multilateral implementation decision may not stop it happening. This makes it all the more important to think carefully through the real downside of SRM, fatal in the eyes of many: its side effects.[27]

A number of these are predictable, and open to research and modeling. Reducing the amount of sunlight reaching the earth is likely to affect precipitation, ocean currents, and photosynthesis. There could be rainforest contraction, changes in monsoon cycles and in the El Niño, and crop reductions.[28] Moreover, some regions might experience far greater and more harmful side effects than others. A small overall effect on rainfall, for example, might mask significantly drier conditions at certain latitudes, and significantly increased wetness in others.[29] As well as this, the presence of sulphur in the atmosphere could lead to ozone destruction.[30] Perhaps most seriously, SRM merely counters temperature but does nothing about the raised level of atmospheric carbon dioxide, which does not just cause a greenhouse effect but also makes the oceans more acid, with potentially serious effects on ocean life and many different food chains, including our own.[31] Using SRM to counter global warming could therefore leave at least one of the other unpleasant effects of fossil-fuel use unaffected.

In some places the side effects might be catastrophic, whereas in others they might not be—and might even be regarded as an acceptable price for cooling, although this would be of little comfort to the region or community whose climate, agriculture, or territory is devastated by floods or other events. There are issues of justice to be considered as well as total welfare, and of course issues of conflict: environmental problems lead to migration and battles over resources which may in turn extract a high human, environmental, and political toll.[32]

Thus the SRM picture is far more complex and many-sided than the launch of a few boats or planes, followed by a temperature change, might suggest. Yet the side effects do not provide an immediate reason to reject SRM. Many of them are still being researched, and in some cases there are suggestions that they may be manageable: ozone destruction might not be excessive and ocean acidification might be treatable by adding minerals.[33] When a powerful new drug is

[26] John Virgoe, *International Governance of a Possible Geoengineering Intervention to Combat Climate Change*, 95 Climatic Change 103 (2009); David Victor, *On the Regulation of Geoengineering*, 24 Oxford Review of Economic Policy 322 (2008); Edward A. Parsons, *Reflections on Air Capture: The Political Economic of Active Intervention in the Global Environment*, 74 Climatic Change 5 (2006).

[27] See pages 30-2 and 50 of the report; Peter G. Brewer, *Evaluating a Technological Fix for Climate*, 104 Proceedings of the National Academy of Sciences 9915 (2007); Alan Robock et al., *A Test for Geoengineering*, 327 Science 530 (2010); Victor, supra note 26, especially citations at 326.

[28] See citations at 29-32 of the report.

[29] Ibid.

[30] Crutzen, supra note 2.

[31] Wigley, supra note 15.

[32] See Victor, supra note 26; Stephen M. Gardiner, *Is "Arming the Future" with Geoengineering Really the Lesser Evil? Some Doubts about the Ethics of Intentionally Manipulating the Climate System*, *in* Stephen M. Gardiner et al., eds., Climate Ethics (2010).

[33] See Lenton and Vaughan, supra note 2; Geoengineering the Climate, 31-2.

shown to have toxic side effects, the answer is not always to abandon the research but to see if the effects can be countered or reduced. SRM may turn out to be a dead end, or it may turn out to be less harmful than is feared. The only certainty at this relatively early stage in the research is that there is no certainty.

The most serious argument against SRM is rather harder to deal with. It is the argument that there will be *unexpected* consequences, and that these may be far worse than any of the expected ones.[34] The argument amounts to "really bad stuff might happen which we haven't even thought of". As the report puts it, there is "indeterminacy" in addition to mere risk.[35] But while indeterminacy is frustrating because it is hard to respond to, it does not mean that it is impossible to assess. The report cites research to the effect that humanity is enamored of easy answers.[36] When technology offers exciting new solutions to problems, we tend to close our eyes to the downsides and allow our optimism free rein. The same species that buys lottery tickets en masse consistently underestimates the problems and complications that will attach to big new projects and overestimates the degree to which they will achieve their goals.

Indeed, an interesting paper by Damon Matthews and Turner, not cited in the report, compares geoengineering with attempts over the years to intervene in complex biosystems, for example by introducing new predators to reduce over-population by certain species.[37] The appropriateness of the analogy is obvious: we have complexity, a natural environment, usually a human-made problem, followed by an attempt to solve that problem by a new counter-intervention. The authors survey the results of a number of such interventions and conclude that on the whole we get it wrong. Side effects are underestimated, the new action quite often makes things worse, and the results are rarely as expected. One might posit a tentative principle that unexpected downsides are to be expected. That would be supported by Victor who notes, also considering geoengineering, that most of the consequences now known to attach to atmospheric nuclear testing were not anticipated, and became apparent only after the testing had occurred.[38] Damon Matthews and Turner suggest that counter-interventions, if they must occur, are most likely to be successful when they take place in a well-understood and confined context, as contrasted with a little-understood context which is densely connected to its surrounding environment. The recommended scenario is of course the precise opposite of the one we find ourselves in with the atmosphere: a less understood and more *connected* natural context could hardly be imagined. It seems that our very experience of our relationship with nature should provide a severe warning against climatic or atmospheric tampering.

[34] Discussed by Schneider, supra note 2; Victor, supra note 26.

[35] Page 38.

[36] Page 44, especially B. Flyvberg, N. Bruzellus, and W. Rothendgatter, Megaprojects and Risk: An Anatomy of Ambition (2003). See also Sven Ove Hansson, *Economic (Ir)Rationality in Risk Analysis*, 22 Economics and Philosophy 231 (2006).

[37] H. Damon Matthews and Sarah E. Turner, *Of Mongooses and Mitigation: Ecological Analogues to Geoengineering*, 4 Environmental Research Letters 045105 (2009).

[38] Victor, supra note 26, at 328.

The difficulty with the above position is this: it is just as true of anthropogenic global warming itself. Pumping carbon dioxide into the atmosphere is an exercise in climatic tampering that also fits the description of what we should not be doing. Since the Earth does not care about our intentions, the environmental difference between emission of carbon dioxide and SRM is just this: the former leads to nasty effects in a warmer world, whereas the latter leads to nasty effects in a cooler world.

The widespread view that SRM should be researched so it can be used in the event that emissions reduction fails and a climatic tipping point approaches suggests that the current thinking is that the ill-consequences of SRM would still be *better* than those of continuing global warming.[39] The Royal Society's report ultimately shares this stance. It envisages SRM as advisable only as an emergency measure which we hope never to have to use, and a very distant second-best to conventional mitigation.[40]

SRM therefore seems to occupy the middle ground in terms of safety in the three options before us. It is more dangerous than reducing CO_2 by either emissions reduction or most forms of CDR, but safer than continuing global warming. A crucial element in deciding what to do about SRM, therefore, is knowing which of the other two scenarios will become actual fact. If we knew that, it would be easy indeed to decide whether to pursue or abandon SRM.

Here we must consider what is usually called the "moral hazard" argument. This is the argument that taking geoengineering seriously is dangerous because it seems to offer a "quick fix" to climate change, with the effect of diminishing public concern about the issue and reducing the chances of emissions reduction. Robock notes that this is the oldest and most ubiquitous argument against geoengineering,[41] yet there is still an absence of research indicating whether or not it is well founded.[42] Nevertheless, the argument is put forward as a reason to be wary of geoengineering, and it is embraced with considerable enthusiasm by some environmental groups.[43] The report notes the importance of the argument to policy, describing it as one of the "main objections" to geoengineering,[44] and quite rightly indicates that research into its validity needs to be done.[45]

[39] The view taken by most writers. Influential examples: Crutzen, supra note 2; Schneider, supra note 2; Virgoe, supra note 26; Peter G. Brewer, *Evaluating a Technological Fix for Climate*, 104 Proceedings of the National Academy of Sciences 9915 (2007). Cf. Stephen M. Gardiner, *Is "Arming the Future" with Geoengineering Really the Lesser Evil? Some Doubts about the Ethics of Intentionally Manipulating the Climate System*, *in* Stephen M. Gardiner et al., eds., Climate Ethics (2010).

[40] Pages 57-8.

[41] Alan Robock, *20 Reasons Why Geoengineering May be a Bad Idea*, 64 Bulletin of the Atomic Scientists 14 (2008). For discussion see Virgoe, supra note 26; David R. Morrow, Robert E. Kopp, and Michael Oppenheimer, *Towards Ethical Norms and Institutions for Climate Engineering Research*, 4 Environmental Research Letters 045106 (2009); Edward A. Parsons, *Reflections on Air Capture: The Political Economic of Active Intervention in the Global Environment*, 74 Climatic Change 5 (2006); Stephen H. Schneider, *Earth Systems: Engineering and Management*, 409 Nature 417 (2001).

[42] Page 39.

[43] Page 37, and submissions cited on that page.

[44] Page 39.

[45] Pages 4, 37, 39, 43.

Implicit in any such opposition to geoengineering is the belief that it would always be possible to do geoengineering later—that we should not be considering it now because, if necessary, we can always deploy it when the actual crisis moment approaches, that is, when it is clear that mitigation is no longer an option. The moral hazard argument therefore contains a gamble and an assumption. The gamble is that it would be possible to develop geoengineering techniques very quickly; the assumption, as I have already indicated, is that taking geoengineering seriously does in fact hold up mitigation.

The gamble does not seem out of tune with the literature on sulphur SRM, which tends to emphasize that it is primarily the side effects which need to be researched. Implementation of the technique itself is not the main difficulty. One gets the impression that indeed it could be done at relatively short notice—the Royal Society's report suggests that it could be implemented within a "decade or two".[46] Nevertheless, it seems reasonable to assume that further research would certainly lead to better SRM techniques, and to techniques that would minimize side effects. It is therefore hard to imagine that deferral of such research would be without costs. So the hope of the moral hazard proponents must be that those costs would be offset by the increased chance of successful mitigation in the absence of active pursuit of SRM.

Yet precisely this assumption, that neglecting SRM would increase the chance of mitigation, is open to doubt. It has been suggested, in opposition, that geoengineering might be regarded as so threatening or frightening by some people or states that it might actually motivate them to mitigate more.[47] Alternatively, by establishing the problem as a serious one, exploration of geoengineering options might galvanize the global community's commitment to mitigation efforts.[48] Geoengineering might also influence those for whom hostility to emissions reductions and skepticism about anthropogenic climate change are symbiotically linked. It could transform the debate in these quarters from "climate change—real or not?" to "climate change—best solution?" Would that be progress? The trade-offs involved are complex. In any case, in response to the moral hazard argument one might finally say that, in the interests of credibility, one must assess facts and research to do with climate change with absolute openness and objectivity, whether they are politically convenient or not. It will take a lot of thinking to work out which dynamic is the most plausible. Ultimately, only political, and perhaps scientific, experimentation will tell us how geoengineering influences the wider climate discussion.

The report's chapter on governance suggests as much. It also looks at other factors relevant to the policymaker, who must decide what he or she should do with the current state of geoengineering knowledge. The problems discussed above of unpredicted side effects and localized harm, as well as the ethical arguments about the morality and justice of climate management, are all surveyed. As one would expect, the precautionary principle is discussed, although to the authors' credit

[46] Page 50.

[47] Sarah Polborn and Felix Tintelnot, *How Geoengineering May Encourage Carbon Dioxide Abatement*, Center for Research on International Financial and Energy Security Working Paper (2009), at <crifes.psu.edu>.

[48] Damon Matthews and Turner, supra note 37. See also page 43 of the report.

they do not make it a central idea, for it offers only weak guidance: the real challenge is not deciding whether to be precautionary but identifying what the most precautionary option is. For example, a decision not to pursue geoengineering will not be precautionary if the result is global warming. Nor will a political commitment to emissions reduction be precautionary if it is rejected by the public and leads to a backlash. Indeed, the chapter devotes quite some space to the important question of how the public will feel about geoengineering and the best way to engage civil society in decision-making about it. Constructive and informed public involvement is likely to be a precondition for stable policy. At root, the future of geoengineering is, like the future of climate change, determined by public attitudes and perceptions. That makes political analysis and prediction a large part of determining the most precautionary path.

The other governance issue which is highlighted in the report is how geoengineering would be managed were it ever to be multilaterally adopted.[49] The authors note that this raises issues of decision-making and of commitment. How would we decide what temperature to set the Earth at? How would we decide when danger is so imminent that geoengineering should start? What would be the liability towards those suffering local consequences?[50] There is a remarkable absence of law directly relevant to climate manipulation done for peaceful purposes.[51] Geoengineering is essentially *intentional* climate change. Once intervention begins or is imminent, the questions of responsibility and compensation would flow freely.

While these governance challenges need thinking through, they are not in principle insurmountable. All collective international action raises such issues.[52] Yet the report adopts the view that geoengineering would be an open-ended commitment, for if SRM were to be suddenly stopped there would probably follow a temperature "rebound", a sudden and dramatic rise in temperature resulting from the raised carbon-dioxide levels that were no longer being counteracted by increased albedo.[53] The suddenness of this change could bring even worse consequences than a gradual rise in temperature. It would therefore be risky to walk away from an SRM process once begun, prior to developing a technique to remove the greenhouse gases from the atmosphere. The report suggests that before SRM is commenced there would have to be an exit strategy, perhaps involving CDR techniques, which tend to be much slower than SRM.[54] As well as this, it seems very likely that any institutions set up to manage SRM would find themselves—as a result of side

[49] See generally Victor, supra note 26; Virgoe, supra note 26; Schneider, supra note 2; Thomas Schelling, *The Economic Diplomacy of Geoengineering*, 33 Climatic Change 303 (1996).

[50] Some of the liability issues are discussed, directly or indirectly, in Alan Robock et al., *A Test for Geoengineering*, 327 Science 530 (2010); David A. Grossman, *Warming Up to a Not-so-Radical Idea: Tort-Based Climate Change Litigation*, 28 Colum. J. Envtl L. 1 (2003); Michael G. Faure and André Nollkaemper, *International Liability as an Instrument to Prevent and Compensate for Climate Change*, 26A Stan. J. Int'l L. (2007).

[51] Daniel Bodansky, *May we Engineer the Climate?*, 33 Climatic Change 309 (1996); Scott, supra note 9; Gareth Davies, *The Law and Policy of Unilateral Geoengineering*, *in* Hélène Ruiz Fabri, Rüdiger Wolfrum, and Jana Gogolin, eds., 2 Select Proceedings of the European Society of International Law 627 (2010).

[52] See Schelling, supra note 49.

[53] H. Damon Matthews and Ken Caldeira, *Transient Climate-Carbon Simulations of Planetary Geoengineering*, 104 Proceedings of the National Academy of Sciences 9949 (2007); page 32 of the report.

[54] Page 45.

effects—dealing with a number of environmental issues in addition to setting global temperature. No body has yet wielded power akin to having a hand on the "global thermostat"—as a leading researcher quoted in the report puts it.[55]

What should one conclude from all this? Where should we now go with geoengineering? A survey of the literature suggests that most positions on the topic are summarized rationally and thoughtfully in the report's pages. It is with heightened expectations, therefore, that one turns to the authors' general discussion (chapter 5) and conclusions and recommendations (chapter 6).

There are a number of sensible and perhaps inevitable conclusions scattered throughout the discussion chapter, including these: that there is not enough evidence to take well-informed decisions on the acceptability of geoengineering techniques; that it would be desirable to have a multilateral governance framework in place before implementing geoengineering on any significant scale; that more research is necessary; and that there should be international oversight of such research which should be "open, coherent, and as internationally coordinated as possible".[56] The report estimates that such a research programme could "reduce many of the uncertainties within ten years, and is therefore recommended".[57] On the individual types of geoengineering, the discussion reflects the findings of the earlier chapters: that CDR would probably be safe, slow, of variable effectiveness, and expensive, and not likely to create transboundary governance problems or conflicts; whereas some forms of SRM would be quick, cheap, effective, risky, governance-intense, and potentially conflict-generating.

The authors make seven recommendations in their concluding chapter. Five of them are fairly predictable: differences between types of geoengineering should be taken into account in evaluating them; the Royal Society and other appropriate bodies should initiate a process of engagement with the public; governance problems should be explored in more detail and processes established to resolve them; there should be a code of practice for geoengineering research; and prior to large scale experiments or deployment of geoengineering there should be consideration of legal, environmental, and other problems. Then come two recommendations which depend on an evaluation of the findings of the report. The first urges increased efforts to cut emissions, saying that "nothing now known" about geoengineering provides any reason to reduce these efforts.[58] The second reiterates that "geoengineering methods are not a substitute for climate change mitigation", and states that CDR is ultimately preferable to SRM, and that SRM should only be applied as an emergency measure.[59]

One may criticize these recommendations for their final choice of emphasis. The message in the report's preceding chapters is that we need to know more about the risks of SRM. Not

[55] Page 40.
[56] Page 52.
[57] Page 52.
[58] Page 57.
[59] Page 58.

having a recommendation that SRM, particularly sulphur- and cloud-based SRM, be made a research priority, so that it can be either promoted up, or struck from, the policy agenda, is puzzling. Another criticism could leveled against the finding that geoengineering is no substitute for conventional mitigation. The report seems here to assume the result of all the research that has not yet been done. The conclusion which the current research on SRM actually supports is that it could, perhaps, be a partial or complete substitute for conventional mitigation, possibly in combination with other measures to combat side effects, but we will not know whether that is so until we research the question further.

In general, the conclusion is regrettably lukewarm. There is no statement of the particular and exceptional importance of geoengineering research, yet surely such a statement is justified by the potential, risks, and uncertainties which surround it. It should be the central finding of the report. By contrast, the conclusion's tone is restrained, almost apologetic at times. On its penultimate page the report says "funding at a level of a few percent of the modest amount spent on R&D for new energy technology would be sufficient to enable substantial progress".[60] Later the report says that sulphur-based SRM should have the highest research priority among the SRM methods, while cloud enhancement "should be investigated, but at a lower priority" uncertainty about its effectiveness apparently being a reason to research less rather than more.[61] Each statement is defensible on its own, but in context it is part of an outlook in which the urgency and importance of geoengineering research are downplayed.

I conclude on a more reflective note. Geoengineering asks us to think about our relationship with the environment in a different way. The philosophy of most environmentalism is conservative, in that it asks us to leave the world untouched. We should respect nature, and adapt to it, but not change it. We are invited to subordinate ourselves to this greater natural whole. Geoengineering is more anthropocentric. It suggests that we are the masters of our environment, and asks us to act as managers of it. It invites both hubris and responsibility. Implicitly, it approves the idea that the world is a resource to be directed for our own good. Human experience of science and technology suggests that the unthinkable often becomes the possible. It seems likely that we will at some point develop the skills necessary to control global temperature. That may come too late for climate change, so geoengineering may be no answer to that problem. The long-term importance of geoengineering may then be in its invitation to us to rethink what we wish our relationship with the planet to be. It is possible that we will choose romantic freedom over power. A return to a simpler life would in many ways be liberating. Climate change could mark the peak of our interference with nature, and which point, in the face of catastrophe, we chose to retreat. Or, alternatively, we may continue along an instrumental path. Climate policy may join social policy and public-health policy as just another example of collective control over the circumstances in which we live. Which of these paths we prefer depends partly upon our perception of our own wisdom, and partly upon our view of our place in the world.

[60] Page 61.
[61] Page 61.